AFRL-SR-AR-TR-04-
0622

REPORT DOCUMENTATION PAGE

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
20/11/2004	Interim Technical Report	01/09/03 – 31/08/04

4. TITLE AND SUBTITLE
Dynamics of Droplet Collision and Flamefront Motion

5a. CONTRACT NUMBER

5b. GRANT NUMBER
F49620-03-1-0136

5c. PROGRAM ELEMENT NUMBER
61102F

6. AUTHOR(S)
Chung K. Law

5d. PROJECT NUMBER
2308

5e. TASK NUMBER
BV

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Department of Mechanical and
Aerospace Engineering
Princeton University
Princeton, NJ 08544

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
AFOSR/NA
801 North Randolph Street
Room 732
Arlington VA 22203-1977

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The present program aims to study the dynamics of droplet collision and flame-flow interaction that are of relevance to liquid-fueled turbulent combustion in propulsive devices. During the reporting period three classes of phenomena were investigated, namely: (1) The dynamics of binary droplet collision, especially on the criterion for the breaking of the inter-droplet surfaces which enables droplet merging. (2) The dynamics of droplet-film collision, especially on the influence of the film thickness in effecting droplet bouncing versus absorption. (3) The dynamics of droplet-droplet collision of dissimilar liquids, showing that the initiation of droplet internal superheating and hence microexplosion can be greatly facilitated by the presence of air bubbles entrained upon coalescence of the colliding droplets.

15. SUBJECT TERMS
Droplet collision; droplet-film collision; van der Waals force; droplet bouncing; droplet coalescence; microexplosion.

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE	UL	6	Mitat Birkan
Unclassified	Unclassified	Unclassified			19b. TELEPHONE NUMBER *(include area code)* (703) 696-8234

Interim Technical Report

(September 1, 2003 to August 31, 2004)

DYNAMICS OF DROPLET COLLISION AND FLAMEFRONT MOTION

(AFOSR F49620-03-1-0136)

Submitted By:

Chung K. Law

Department of Mechanical and Aerospace Engineering

Princeton University, Princeton, NJ 08544

Phone: 609-258-5178

Fax: 609-258-6233

E-Mail: cklaw@princeton.edu

For Consideration By:

Dr. Mitat Birkan

Air Force Office of Scientific Research

Introduction

During the reporting period three classes of phenomena were investigated, namely: (1) The dynamics of binary droplet collision, especially on the criterion for the breaking of the inter-droplet surfaces which enables droplet merging. The role of the van der Waals force in surface attraction was simulated. (2) The dynamics of droplet-film collision, especially on the influence of the film thickness in effecting droplet bouncing versus absorption, which is facilitated when the film thickness is comparable to the droplet diameter. (3) The dynamics of droplet-droplet collision of dissimilar liquids, showing that the initiation of droplet internal superheating and hence microexplosion can be greatly facilitated by the presence of air bubbles entrained upon coalescence of the colliding droplets.

1. Dynamics of Binary Droplet Collision

Our previous studies on binary droplet collision revealed a non-monotonic outcome in terms of merging and bouncing as the collision intensity is varied. Phenomenologically, the propensity for bouncing or merging is a consequence of the readiness with which the gaseous mass in the inter-droplet gap can be squeezed out of the gap by the colliding interfaces such that they can make contact at the molecular level, leading to their destruction and thereby resulting in merging.

The lack of a clear criterion on the instant of surface rupture has however caused considerable uncertainty in the computational simulation of the collision event and consequently understanding of the collision and merging dynamics. The present study was motivated by our experimental observation that the occurrence and instant of merging could be identified through a distinct change in the cuspy contour of the imaged interface, and the recognition that such an instant could be time resolved with sufficient accuracy such that, by using it as an input to the computational simulation based on continuum mechanics, the evolution of the experimental collision images subsequent to merging could be satisfactorily simulated.

Having established the adequacy of this empirically enabled computational simulation approach, we further studied the various issues related to the merging and bouncing aspects of the collision dynamics, including the energy budget, the flow field characteristics, and evolution of the geometry and dynamics of the inter-droplet gap, with emphasis on the transition between bouncing and merging regimes, and the differences between soft and hard collisions. The possible role of the van der Waals force in effecting merging was investigated, and the potential importance of compressibility and rarified gas effects for a complete description of the merging dynamics identified.

This work is reported in Publications [1, 2].

2. Dynamics of Droplet-Film Collision

In addition to droplet-droplet collision, droplet-surface collision is also of practical importance in the performance of spray-fueled combustors. Extensive experiments were conducted for the impingement of tetradecane droplets onto a surface wetted by the same fluid. Results showed that the collision outcome depends sensitively on two parameters, namely the film thickness relative to the droplet radius, and the impact inertia characterized by the droplet Weber number. It was found that bouncing and coalescence are respectively favored for small and large We, which is reasonable. Furthermore, there exists a range in We over which merging is favored when the film thickness is of the order of the droplet diameter. The merging mechanism based on simulation appears to be different in this regime than in either the thin film or the deep pool regimes. Extensive experimentation is being performed to verify this conjecture.

This work is reported in Ref. [3].

3. Micro-explosion of Collision-generated Droplets

Our studies on binary droplet collision has yielded an unexpected phenomenon that could have significant implications in understanding and optimizing spray combustion, namely the occurrence of mico-explosion of droplets of multicomponet fuels. To appreciate the relation between droplet collision and micro-explosion, we first note that it is well established that multicomponent droplet could undergo microexplosion when the volatile components diffusionally trapped within the droplet interior could become

superheated and homogeneously nucleate. Furthermore, when two colliding droplets merge, an air bubble is trapped inside the merged mass. It is then quite reasonable to anticipate that this trapped bubble could facilitate the nucleation of the superheated liquid.

Two projects were undertaken to explore the phenomenon of collision-facilitated micro-explosion. The first project involved the collision between two droplets of high and low volatilities, respectively, such as heptane and hexadecane. Results conclusively demonstrated that while droplets of such a bi-component fuel do not micro-explode, they readily undergo micro-explosion when they were produced through collision. The second project involved the collision between an oil droplet and a water droplet. Because of the immiscible nature of water and oil, it was found that upon collision the water is usually embedded within hexadecane. Thus upon complete gasification of hexadecane which has a higher boiling point, the superheated water is exposed to the gaseous environment and flash vaporizes. In both cases the droplet lifetime is substantially reduced.

These works are respectively published in Refs. [4, 5].

Publications

1. "On the dynamics of head-on droplet collision: experiment and simulation," by K.L. Pan and C.K. Law, Paper No. AIAA 2004-1159, 42nd Aerospace Sciences Meeting, Reno, NV, Jan. 5-8, 2004.

2. "Experimental and mechanistic descriptions of merging and bouncing in head-on binary droplet collision," by K.L. Pan, B. Zhou, and C.K. Law, submitted for publication.

3. "Dynamics of droplet-film collision," by K.L. Pan and C.K. Law, Paper No. AIAA-2005-0352, 43rd Aerospace Sciences Meeting, Reno, NV, Jan. 10-13, 2005.

4. "On the burning and microexplosion of collision-generated bi-component droplets: miscible fuels," by C.H. Wang, W.G. Hung, S.Y. Fu, W.C. Huang, and C.K. Law, *Combustion and Flame*, Vol. 134, pp. 289-300 (2003).

5. "On the burning characteristics of collision-generated water/hexadecane droplets," C.H. Wang, W.G. Hung, S.Y. Fu, W.C. Huang, and C.K. Law, *Combustion Science and Technology*, Vol. 176, No. 1, pp. 71-93 (2004).

Participants

Chung K. Law, Principal Investigator

Kuo L. Pan, Graduate Student (Ph.D awarded, June, 2004)

Albert Hsieh, Graduate Student

Delin Zhu, Research Staff

Ching H. Wang, National Taiwan University (Faculty Collaborator)